Original Article

Effects of a Running Bout in the Heat on Cognitive Performance

David Jiménez-Pavón[1,2], Javier Romeo[3], Mónica Cervantes-Borunda[4], Francisco B. Ortega[2,5], Jonatan R. Ruiz[5,6], Vanesa España-Romero[5,7], Ascensión Marcos[3], Manuel J. Castillo[2]

[1]*GENUD (Growth, Exercise, Nutrition and Development) Research Group, E.U. Ciencias de la Salud, Universidad de Zaragoza, SPAIN*
[2]*Department of Medical Physiology, School of Medicine, University of Granada, SPAIN*
[3]*Immunonutrition Research Group, Department of Metabolism and Nutrition (hasta aquí todo bien), Institute of Food Science and Technology and Nutrition (ICTAN), Spanish National Research Council (CSIC), Madrid, SPAIN*
[4]*Faculty of Physical Activity and Sport, University of Chihuahua, MEXICO*
[5]*Unit for Preventive Nutrition, Department of Biosciences and Nutrition at NOVUM, Karolinska Institute, Huddinge, SWEDEN*
[6]*Department of Physical Education and Sport, University of Granada, Granada, SPAIN*
[7]*Department of Exercise Science, University of South Carolina, Columbia, South Carolina, USA*

The aim of this study was to examine the effect of a running bout under hot conditions on cognitive performance in physically active men. Sixteen participants ran at 60% of maximum aerobic speed for an average time of 52.4 ± 7.6 minutes under hot environmental conditions (35°C, 60% relative humidity). Changes in body mass, lean mass, hematocrit, plasma volume, serum urea, creatinine, and thirst score were assessed to evaluate the state of hydration immediately before and after exercise. Cognitive performance was assessed using the Vienna Test System battery before and after exercise. The running protocol led to a decreased body mass, lean mass, plasma volume and an increased hematocrit, serum urea, creatinine and thirst score (all $p < 0.05$), implying that there was significant impairment in the state of hydration. After the running bout, complex and peripheral reaction time consistently improved, whereas visual angle was impaired (all $p < 0.05$). A running bout in the heat improves the speed of response in complex tasks but impairs the field of vision and leads to a deleterious hydration state. [*J Exerc Sci Fit* • Vol 9 • No 1 • 58–64 • 2011]

Keywords: body mass, exercise, heat, reaction time, visual angles

Introduction

In many geographical regions in the world, sports and physical and recreational activities often take place under high ambient temperature conditions. This is the case, for instance, in Mediterranean countries. The effect of exercise in the heat can be harmful, affecting different physiological and psychological aspects, including cognitive performance (Grandjean & Grandjean 2007).

The effect of heat and exercise exposure on cognitive performance is a rather new and unknown field in exercise physiology, and the findings have so far been contradictory (Lieberman 2007). Submaximal aerobic exercise performed for periods of up to 60 minutes seems to facilitate specific aspects of information processing (Tomporowski 2003). However, several studies have reported impairments on cognitive performance when 2% or more of body mass is lost due to heat,

Corresponding Author
David Jiménez-Pavón, Department of Medical Physiology, School of Medicine, University of Granada, Avd. Madrid s/n. CP: 18012, Granada, SPAIN.
E-mail: davidjimenez@ugr.es

ELSEVIER

physical exertion and/or water restriction (Grandjean & Grandjean 2007; Lieberman 2007; Tomporowski 2003; Cian et al. 2001, 2000; Gopinathan et al. 1988; Sharma et al. 1986).

Most of the previous research has focused mainly on the study of cognitive functions such as response speed and accuracy, fatigue, short-term memory and mood (Colcombe et al. 2003; Tomporowski 2003; Brisswalter et al. 2002; Hockey 1997; Hancock & Warm 1989). Studies describing the effects of exercise under hot environmental conditions on peripheral perception function (i.e., visual field and peripheral vision reaction time), fundamental aspects of sport, physical and recreational activities and its safety are scarce. Only one study has focused on the effect of exercise in the heat in high performance athletes (Bursill 1958). In that study, participants responded to random peripheral signals while engaged in a continuous central task. No significant decrements were found, but Bursill (1958) observed a funnelling of peripheral awareness towards the central field of vision in a high proportion of the participants. Since in many sports (i.e., team sports) and recreational activities, peripheral perception plays a key role in adequate and safe practice, it is important to better understand the influence of exercise under heat (i.e., in Mediterranean regions) on the cognitive performance of people who are physically active, in sport practitioners or even physiologists and coaches.

This study aimed to describe the effects of a running bout under hot environmental conditions on the cognitive performance of physically active men.

Methods

Study design

An experimental study was conducted to examine how a running bout under hot environmental conditions affects cognitive performance. A full set of measurements, i.e., cognitive performance, blood parameters and body composition, was performed in that order immediately before and after the running protocol. The study design is depicted in Figure 1. Temperature (35 ± 1°C) and relative humidity (60 ± 2%) in the laboratory were kept constant with the electronic heating system and continuously checked using a portable digital weather tracker (Radio Control; Oregon Scientific Inc., Tualatin, OR, USA). The heating system was switched on and the temperature was set to 35°C a few hours before the start to give the laboratory time to heat up to 35°C.

Subjects

Twenty-two healthy physically active men voluntarily took part in the study. Participants were briefed about the characteristics of the study and signed informed consents. The study protocol was performed in accordance with the ethics standards established in the 1961 Declaration of Helsinki (as revised in Hong Kong in 1989, and in Edinburgh in 2000). The study was approved by the Review Committee for Research Involving Human Subjects of the University of Granada. The participants were asked to avoid strenuous exercise, and not to consume alcohol or take medication in the 2 days prior to the study. In addition, the participants were asked to follow a hydration protocol. Body mass was assessed over a period of 1 week to ensure a hydrated state. Six subjects did not fulfil all of the inclusion criteria (see below) and were excluded from the analysis. The final study sample was 16 men.

Inclusion criteria

Participants were asked about their physical activity levels and considered to be physically active if they undertook a minimum of 4 times/week of physical activities or exercise for at least 1 hour. After doing the specific field test, individuals who reached at least a maximal oxygen consumption ($\dot{V}O_{2max}$) of $50\,mL \cdot kg^{-1} \cdot min^{-1}$, or a maximal aerobic speed (MAS) of $14\,km \cdot hr^{-1}$ were included in the study's analyses. $\dot{V}O_{2max}$, MAS and maximal heart rate (measured using a Polar 720i heart rate monitor; Polar Electro Oy, Kempele, Finland) were assessed using the Université de Montréal Track Test (Léger & Mercier 1983). $\dot{V}O_{2max}$ was estimated using the following equation (Ahmaidi et al. 1992):

$$\dot{V}O_{2max} = 1.353 + (3.163 \times \text{speed in last stage}) + [0.0122586 \times (\text{speed in last stage})^2]$$

The environmental conditions for the field test day were considered standard to an adequate performance in the test (around 20°C).

Running protocol

All the participants performed the running protocol on a treadmill (h/p/cosmos, Nussdorf-Traunstein, Germany). The protocol started with 5 minutes of warm-up at 40% of MAS. The participants were asked to run for 60 minutes at 60% of MAS (average speed: $9.6 \pm 0.6\,km \cdot hr^{-1}$), followed by 5 minutes at 30% of MAS as the cooling down time. Participants who were not able to run for at least 40 minutes were not included in the analysis.

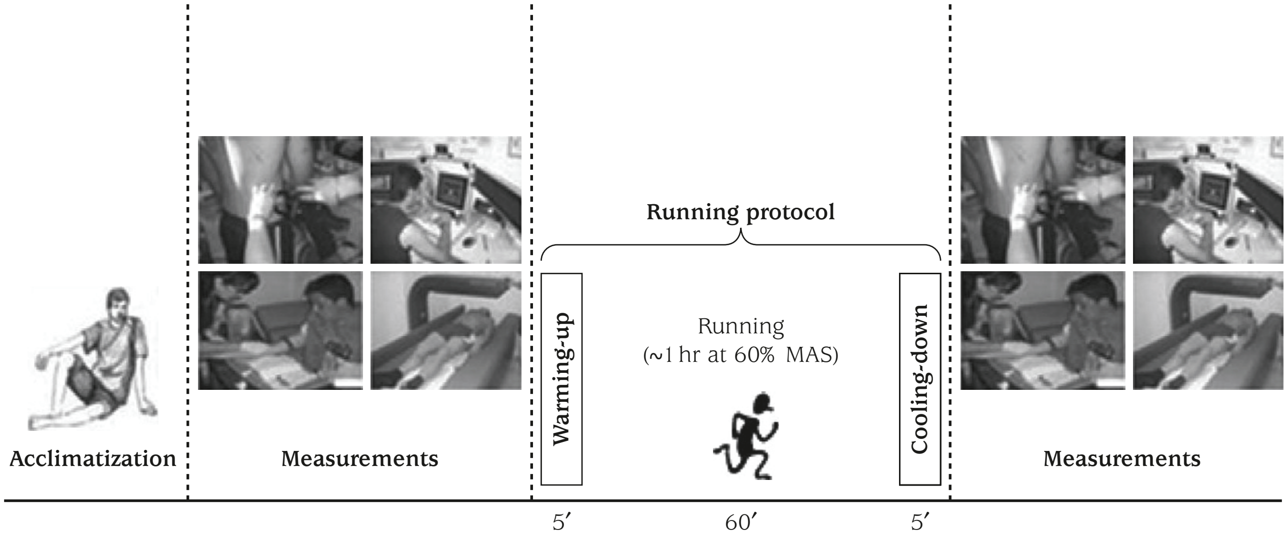

Fig. 1 Graphical illustration of the study design. MAS = maximal aerobic speed.

Seven participants completed the 60-minute running time, while the rest ran for between 40 and 50 minutes. Mean total running time was 52.4 ± 7.6 minutes. The rating of perceived exertion was evaluated just before and after the running protocol using a standardized Borg scale board. The exercise protocol was perceived as hard and increased from 7 to 18 ($p = 0.001$). Maximal heart rate percentage increased from 60% to 95% ($p = 0.001$). Participants were not allowed to drink during the study. A fan was used to facilitate sweat evaporation and thermoregulation. Subjects were advised to wear light clothes (shorts and t-shirt) for their run.

Cognitive performance

Cognitive performance was assessed with four different tests using the Vienna Test System (Schuhfried GmbH, Moedling, Austria) (Figure 2). The second evaluation of cognitive performance (after exercise) was done 15 minutes after the running protocol was finished.

One week prior to the study, all the participants received comprehensive instructions on the tests to be performed. After that, a familiarization session was carried out, during which the cognitive performance tests were performed four times and the scores were stable.

Test 1: Simple reaction time (ms)

The stimulus for perception was a yellow light (flash) that appeared at randomized time intervals on the Vienna Test System device's monitor. The respondent had to react as quickly as possible by pressing the appropriate button on the device's keyboard (Figure 2).

Test 2: Choice reaction time (ms)

The stimulus was a yellow and/or red light that could appear singly or concurrently. The respondent received the following instruction, "Press the appropriate key only when both stimuli are concurrently present".

Test 3: Multiple reaction time (ms) and rate of correct/incorrect reactions (number responses)

The stimuli were visual and acoustic. This was quite a complex and demanding test that required the participant to be able to discriminate among colors and acoustic signals and to choose the relevant reaction according to the assignment rules indicated in the instructions. The difficulty of this test lies in the production of continuous, sustained rapid and varied reactions to rapidly changing stimuli. In this test, there were multiple stimuli of colors (yellow, red, green, blue and white), pedal symbols (right and left), and acoustic stimuli (acute and grave). Colors and pedal symbols appeared on the screen, and the respondent had to react by pressing the appropriate buttons on the panel or on the foot pedals. Acoustic stimuli came from the speakers, and the respondent had to react by pressing the appropriate buttons on the device.

Test 4: Peripheral vision reaction time (ms), field of vision (°), left visual angle (°) and right visual angle (°)

Visual stimuli—produced with light-emitting diodes mounted onto the device—moved along with a pre-set speed (in regular "jumps"). Critical stimuli appeared at pre-set time intervals, to which the participant had to react by pressing the foot pedal while they were

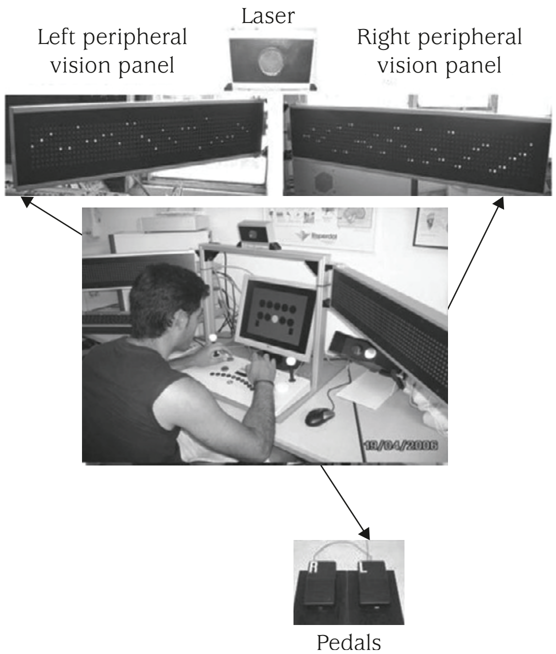

Fig. 2 Device used for cognition assessment: the Vienna Test System.

concurrently engaged in a continuous central task on the device's monitor.

Blood parameters
A blood sample of ~5 mL was taken twice, before exercise after a 1-hour rest period and immediately after exercise, by puncture of the cubital vein with minimum stasis. Plasma volume (mL per 100 mL), hematocrit (%), creatinine ($mg \cdot dL^{-1}$) and urea ($mg \cdot dL^{-1}$) were determined. Hematocrit and hemoglobin were assessed using whole blood collected into EDTA-K3E-Vacutainers (BD, Franklin Lakes, NJ, USA) and measured in an automated analyzer (Technicon H1; Bayer, Tarrytown, NY, USA). Changes in plasma volume were calculated from hematocrit and (reference range 0.5–1.2 $mg \cdot dL^{-1}$) were determined by the Synchron LX system using a Beckman analyzer (Beckman Coulter Inc., Fullerton, CA, USA).

Body composition
Body mass (kg) was measured with a standard balance beam (Seca Vogel & Halke GmbH & Co., Hamburg, Germany; precision of 0.1 kg) with subjects in their underwear only and barefoot. Height (cm) was measured with a stadiometer incorporated in the balance (Seca Vogel & Halke GmbH & Co.; precision of 0.1 cm). Lean mass was measured by full body dual energy X-ray absorptiometry using a Norland XR-46 scanner (Norland, Fort Atkinson, WI, USA).

Thirst perception
Each participant provided a rating of his own thirst perception using a categorical scale, ranging from 1 ("not thirsty") to 10 ("very, very thirsty") as indicated elsewhere (Maresh et al. 2004).

Statistical analyses
The data are presented as mean ± standard deviation. Pre–post running absolute (post-exercise value – pre-exercise value) and percent relative changes ($\% = v \times 100$) were calculated for both hydration and cognitive parameters. The pre–post running changes were analyzed using one-way ANOVA for repeated measures. We also calculated the effect size statistics as Cohen's d (standardized mean differences) (Nakagawa & Cuthill 2007). All the residuals showed a satisfactory pattern.

Statistical analyses were performed with SPSS version 15.0.1 (SPSS Inc., Chicago, IL, USA). The significance level was set at 5%.

Results

The participants' characteristics are shown in Table 1.

Hydration state: pre–post exercise changes
Body mass, lean body mass and estimated plasma volume significantly decreased after running, while serum urea, serum creatinine and thirst score significantly increased (all $p < 0.01$, except plasma volume $p < 0.05$). Small effect sizes were observed for body mass, lean body mass and hematocrit, whereas large effect sizes were observed for plasma volume, serum urea and serum creatinine (Table 2).

Cognitive performance: pre–post exercise changes
Choice reaction time ($p < 0.01$), multiple reaction time ($p < 0.001$) and peripheral reaction time ($p < 0.05$) improved, while right visual angle ($p < 0.05$) was impaired after ~1 hour of running. Simple reaction time, correct responses, field of vision and left visual angle did not significantly change after exercise (Table 3). The number of incorrect responses tended to increase. Small effect sizes were observed for choice reaction time, incorrect reactions and left visual angle, whereas large effect sizes were observed for multiple reaction time, peripheral vision reaction time, field of vision and right visual angle (Table 3).

Discussion

The bout of running under hot environmental conditions led to dehydration in the study participants. As the present study was not designed to analyze the separate influence of heat and dehydration on cognitive performance, we will interpret the result as a combined effect of both factors. These different factors are often present in the Mediterranean countries and other geographical regions in the world. The results suggest that perception–reaction time to stimuli is significantly improved after exercise in complex tasks that require a certain level of processing and attention, such as choice reaction time, multiple reaction time to visual and acoustic stimuli, and when the stimulation is frontal or peripheral. However, the perception functions of field of vision, and left and right visual angles were impaired after the exercise (effect sizes of 0.5, 0.2 and 0.6, respectively), although significant differences were only observed for right visual angle.

These findings are of especial interest for activities and sports in which deterioration in the perception functions (i.e., field of vision) could affect the accuracy of the activity (i.e., hitting the ball in tennis), team sports strategies (i.e., communication between players) or safety (i.e., injuries during practice). Despite improvements in the perception–reaction time of several tests, deterioration in accuracy was noted as a consequence of deterioration in vision performance and increased number of incorrect responses. An interesting finding was that the number of incorrect responses increased by 62% in subjects after ~1 hour of running. Although the difference between pre and post exercise was not significant, we consider that the

Table 1. Characteristics of the study sample ($n = 16$)*

Age (yr)	21.1 ± 1.4 (19.3–24.2)
Body mass (kg)	74.3 ± 6.6 (60.1–85.7)
Height (cm)	178 ± 4 (171–186)
Percentage body fat (%)	14 ± 4 (6–22)
Maximal oxygen uptake ($mL \cdot kg^{-1} \cdot min^{-1}$)	56 ± 4 (49–63)
Maximal aerobic speed ($km \cdot hr^{-1}$)	16 ± 1 (14–18)
Maximal heart rate ($beats \cdot min^{-1}$)	196 ± 7 (183–216)

*Data are presented as mean ± standard deviation (range).

Table 2. Hydration parameters pre- and post-exercise ($n = 16$)*

	Pre-exercise†	Post-exercise†	Change	% change‡	Effect size (Cohen's *d*)
Body mass (kg)	74.2 ± 6.5	72.4 ± 6.4	−1.8 ± 0.3§	−2.4 ± 0.3	0.3
Lean mass (kg)	57.9 ± 4.5	56.6 ± 4.5	−1.3 ± 0.6§	−2.2 ± 1.2	0.3
Hematocrit (%)	45.7 ± 3.0	46.6 ± 2.5	1.0 ± 2.0	2.1 ± 4.1	0.3
Plasma volume (mL per 100 mL)	54.3 ± 3.0	51.9 ± 3.2	−2.4 ± 4.1‖	−5.0 ± 8.5	0.8
Serum urea ($mg \cdot dL^{-1}$)	40 ± 6	47 ± 6	7 ± 3§	14 ± 6	1.2
Serum creatinine ($mg \cdot dL^{-1}$)	1.2 ± 0.1	1.4 ± 0.1	0.2 ± 0.1§	11.6 ± 5.3	2
Thirst score	1 ± 1	9 ± 1	8 ± 1§	800 ± 158	–

*Data are presented as mean ± standard deviation; †pre–post test differences analyzed by one-way repeated-measures ANOVA; ‡% change = [(post-exercise value − pre-exercise value)/pre-exercise value] × 100; §$p < 0.001$; ‖$p < 0.05$.

Table 3. Cognitive performance parameters pre- and post-exercise ($n = 16$)*

	Pre-exercise†	Post-exercise†	Change	% change‡	Effect size (Cohen's *d*)
Simple reaction time (ms)	253 ± 34	251 ± 33	−1 ± 23	−0 ± 8	0.1
Choice reaction time (ms)	383 ± 71	358 ± 61	−25 ± 30§	−6 ± 8	0.4
Multiple reaction time (ms)	654 ± 60	619 ± 60	−36 ± 22‖	−5 ± 3	0.6
Correct reactions (*n*)	16 ± 0	16 ± 0	0 ± 0	1 ± 3	0.0
Incorrect reactions (*n*)	15 ± 11	18 ± 9	3 ± 10	62 ± 117	0.3
Peripheral vision reaction time (ms)	646 ± 77	609 ± 52	−37 ± 71¶	−5 ± 11	0.6
Field of vision (°)	175 ± 9	171 ± 8	−4 ± 9	−3 ± 6	0.5
Left visual angle (°)	93 ± 7	92 ± 4	−1 ± 6	−1 ± 7	0.2
Right visual angle (°)	82 ± 5	79 ± 5	−3 ± 5.67¶	−4 ± 8	0.6

*Data are presented as mean ± standard deviation; †pre–post test differences analyzed by one-way repeated-measures ANOVA; ‡% change = [(post-exercise value − pre-exercise value)/pre-exercise value] × 100; §$p < 0.01$; ‖$p < 0.001$; ¶$p < 0.05$.

increase in the number of incorrect responses after exercise is important in terms of precision (effect size 0.3) because the participants responded faster to the stimulus but with more errors, which translates into a worse result in a specific task (i.e., people playing tennis can react faster but hit the ball with less precision). These findings are in agreement with those of previous reports (Grego et al. 2005; Gopinathan et al. 1988; Leibowitz et al. 1972). Grego et al. (2005) suggested that aerobic exercise initially facilitates cognitive processing but, as exercise continues, increases in central fatigue seem to impair cognitive function by way of a decrease in perceptual response and an increase in errors during complex tasks. So, central fatigue could be one of the possible mechanisms explaining these results.

Though no change occurred in perception–reaction time to a simple stimulus following ~1-hour exercise, we observed consistent improvements in perception–reaction time in more complex tasks, which concur with the results of Leibowitz et al. 1972. The improvement in cognitive performance could be partially explained by the concept of arousal and the hypothetical inverted-U relationship between arousal and performance (Gould & Krane 1992; Yerkes & Dodson 1908). In fact, it has been proposed that arousal attention specially increases up to an optimal level when relevant or complex cues are processed, as may have occurred in our study. It is possible that when complex tasks are required during exercise in which arousal is increased, the organism will pay more attention to improving the reaction time in the complex tasks rather than in simple reaction time, based on the assumption that the latter is probably of less relevance.

Additionally, an increase in arousal leads to a subsequent attention narrowing and even missing of relevant cues (Easterbrook 1959). According to the inverted-U theory, this improvement in complex reaction time could be due to the fact that subjects are in an optimal zone for cognition performance as has been suggested by Grego et al. (2005), who also reported improvements in complex cognitive performance after 1 hour of exercise. In the present study, arousal was not assessed, so we cannot confirm if the improvement is due to it or not.

Our results on peripheral perception function, assessed as field of vision and left and right visual angles, are similar to those reported by Grego et al. (2005). They found an impairment in perceptual response (called peripheral perception function in our study) and an increase in the number of errors in the map recognition task (called incorrect responses in our study). Similarly, other authors have described quicker response times following exercise, but this positive effect is accompanied by an increased number of choice response errors (Hillman et al. 2003). These findings could be explained, at least in part, by a possible interaction between the above described inverted-U theory (Gould & Krane 1992; Yerkes & Dodson 1908) and the impaired hydration state found. It may be in accordance with several authors who affirm that a dehydration level of 2% or more could affect visuomotor skills, short-term memory and cognitive performance (Grandjean & Grandjean 2007; Lieberman 2007; Maughan et al. 2007; Tomporowski 2003). However, the current design of our study does not allow us to confirm this interaction as no data on arousal were recorded.

In conclusion, the results of the present study indicate that in physically active men, a running bout of ~1 hour under hot environmental conditions improves some cognitive performance related to perception–reaction time in complex tasks, but deteriorates those related to field of vision and accuracy and the state of hydration. These results provide useful and relevant information for those recreational activities and sports modalities that usually take place under heat and contribute to better understanding the influence of exercise on cognitive performance. These findings have an especial implication for sport personal trainers or coaches, psychologists and physiologists who should be aware that despite the improvements produced in choice reaction time, multiple reaction time and peripheral reaction time, the overall peripheral function and accuracy of some abilities could be negatively affected after a running bout (~1 hour) under hot environmental conditions (e.g., reduced field of vision to perceive a ball coming).

Acknowledgments

This study was supported by the "Centro de Información Cerveza y Salud", the Spanish Ministry of Science and Innovation (JCI-2010-07055; RYC-2010-05957; EX-2008-0641; EX-2009-0899) and the Swedish Heart-Lung Foundation (20090635). We gratefully acknowledge the help of all the participants who took part in this study for their collaboration. No benefits of any form have been received or will be received from any commercial party related directly or indirectly to the authors.

References

Ahmaidi S, Collomp K, Caillaud C, Prefaut C (1992). Maximal and functional aerobic capacity as assessed by two graduated field methods in comparison to laboratory exercise testing in moderately trained subjects. *Int J Sports Med* 13:243–8.

Brisswalter J, Collardeau M, Rene A (2002). Effects of acute physical exercise characteristics on cognitive performance. *Sports Med* 32: 555–66.

Bursill AE (1958). The restriction of peripheral vision during exposure to hot and humid conditions. *Q J Exp Psychol* 10:113–29.

Cian C, Barraud PA, Melin B, Raphel C (2001). Effects of fluid ingestion on cognitive function after heat stress or exercise-induced dehydration. *Int J Psychophysiol* 42:243–51.

Cian C, Koulmann N, Barraud P, Raphel C, Jiménez C, Melin B (2000). Influence of variations in body hydration on cognitive function: effect of hyperhydration, heat stress, and exercise-induced dehydration. *J Psychophysiology* 14:29–36.

Colcombe S, Kramer AF (2003). Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychol Sci* 14:125–30.

Easterbrook JA (1959). The effect of emotion on cue utilization and the organization of behavior. *Psychol Rev* 66:183–201.

Gopinathan PM, Pichan G, Sharma VM (1988). Role of dehydration in heat stress-induced variations in mental performance. *Arch Environ Health* 43:15–7.

Gould D, Krane V (1992). The arousal-athletic performance relationship: current status and future directions. In: Horn TS (Ed.), *Advances in Sport Psychology.* Human Kinetics, Champaign, IL, pp. 119–41.

Grandjean AC, Grandjean NR (2007). Dehydration and cognitive performance. *J Am Coll Nutr* 26(5 Suppl):549S–54S.

Grego F, Vallier JM, Collardeau M, Rousseu C, Cremieux J, Brisswalter J (2005). Influence of exercise duration and hydration status on cognitive function during prolonged cycling exercise. *Int J Sports Med* 26: 27–33.

Hancock PA, Warm JS (1989). A dynamic model of stress and sustained attention. *Hum Factors* 31:519–37.

Hillman CH, Snook EM, Jerome GJ (2003). Acute cardiovascular exercise and executive control function. *Int J Psychophysiol* 48:307–14.

Hockey GR (1997). Compensatory control in the regulation of human performance under stress and high workload; a cognitive-energetical framework. *Biol Psychol* 45:73–93.

Léger L, Mercier D (1983). Cofit energetique de la course sur tapis roulant et sur piste. *Motricité Humainer* 2:66–9.

Leibowitz HW, Abernethy CN, Buskirk ER, Bar-or O, Hennessy RT (1972). The effect of heat stress on reaction time to centrally and peripherally presented stimuli. *Hum Factors* 14:155–60.

Lieberman HR (2007). Hydration and cognition: a critical review and recommendations for future research. *J Am Coll Nutr* 26(5 Suppl): 555S–61S.

Maresh CM, Gabaree-Boulant CL, Armstrong LE, Judelson DA, Hoffman JR, Castellani JW, Kenefick RW, Bergeron MF, Casa DJ (2004). Effect of hydration status on thirst, drinking, and related hormonal responses during low-intensity exercise in the heat. *J Appl Physiol* 97:39–44.

Maughan RJ, Shirreffs SM, Watson P (2007). Exercise, heat, hydration and the brain. *J Am Coll Nutr* 26(5 Suppl):604S–12S.

Nakagawa S, Cuthill IC (2007). Effect size, confidence interval and statistical significance: a practical guide for biologists. *Biol Rev Camb Philos Soc* 82:591–605.

Sharma VM, Sridharan K, Pichan G, Panwar MR (1986). Influence of heat-stress induced dehydration on mental functions. *Ergonomics* 29:791–9.

Tomporowski PD (2003). Effects of acute bouts of exercise on cognition. *Acta Psychol (Amst)* 112:297–324.

Yerkes RM, Dodson JD (1908). The relation of strength of stimulus to rapidity of habit-formation. *J Com Neurol Psychol* 18:459–82.